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Cw hyper-Raman laser and four-wave mixing in atomic sodium

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Abstract

Continuous wave hyper-Raman (HR) generation in a ring cavity on the 6s → 4p transition at 1640 nm in sodium is realized for the first time by two-photon excitation of atomic sodium on the 3s → 6s transition with a continuous wave (cw) dye laser at 590 nm and a single frequency argon ion laser at 514 nm. It is shown, that the direction and efficiency of HR lasing depends on the propagation direction of the pump waves and their frequencies. More than 30% HR gain is measured at 250 mW of pump laser powers for counter-propagating pump waves and a medium length of 90 mm. For much shorter interaction lengths and corresponding focussing of the pump waves a dramatic increase of the gain is predicted. For co-propagating pump waves, in addition, generation of 330 nm radiation on the 4p → 3s transition by a four-wave mixing (FWM) process is observed. Dependencies of HR and parametric four-wave generation have been investigated and will be discussed.

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1. Introduction

The study of resonant interactions in coupled level schemes has gained some interest during the past years, as in such configurations coherent coupling and interference processes play an important role, leading to novel effects and applications. For example in Λ-type (Raman coupled) level schemes dark resonances with very narrow spectral structures appear [1,2] which allow applications in precision spectroscopy, compact atomic clocks [3] and magnetometry [4].

Coherent coupling has been used to manipulate absorption and dispersion [5] and serves also as a

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basis for all attempts to reduce the requirements for lasers, such as the realization of amplification or lasing without inversion [6]. For some reviews and basic calculations of coherent interactions in coupled level schemes, see [7–9] and further references given therein.

Considering resonant parametric (closed cycle) processes such as the four-wave interaction schemes outlined in Fig. 1, different nonlinear processes actually may contribute to the generation of a new field, such as ω_4. This is especially the situation for the difference-sum mixing $\omega_1 - \omega_2 + \omega_3 = \omega_4$ (Fig. 1(b)) and sum-difference mixing schemes $\omega_1 + \omega_2 - \omega_3 = \omega_4$ (Fig. 1(c)), where four-wave mixing (FWM), Raman or hyper-Raman (HR) and parametric amplification processes are involved. Especially the scheme of Fig. 1(b), often referred as double Λ-configuration, is a subject of many theoretical and experimental investigations [10]. We studied in the past this scheme, using diatomic sodium molecules generated in a heatpipe as nonlinear material, and could demonstrate efficient and powerful (for a cw process) generation of radiation at frequency ω_4 [11]. To achieve optimum conversion and output power, the field intensities and frequency detunings have to be optimized, as at high pump intensities dynamic Stark splitting of the levels occurs, leading to a rich spectral structure which influences the conversion [12,13]. Instead of applying three external fields (ω_1,ω_2,ω_3) for the mixing process, it is also possible to use only two external pump fields (ω_1,ω_3) and to generate the field ω_2 internally by a cw Raman process excited with the field ω_1. For the operation of cw Raman lasers in sodium molecules see [14]. This operation obviously indicates that coupling between nonlinear processes should be involved. In this scheme the field ω_4 is generated at a ground state resonance transition where, without the pump fields, strong absorption occurs. The effective and powerful generation may therefore be interpreted by an absorption reduction due to the Raman coupling or by an absorption overcompensation due to a gain process. In fact, in some recent investigations, parametric amplification of the field ω_4 and a coupling of the Raman gain and parametric gain has been demonstrated [15].

In this contribution, we extend the investigations to the level configuration of Fig. 1(c), where the fourth-wave generation ω_4 is coupled to a two-photon pumped HR gain and oscillation process. Sodium atoms, generated in a heatpipe, are used as nonlinear medium. By two-photon excitation (ω_1,ω_2) of Na on the 3s → 6s transition cw HR lasing on the 6s → 4p transition is obtained (Fig. 2). This HR lasing process is investigated for co- and counter-propagating two-photon excitation. For the co-propagating (collinear) pumping geometry the HR emission (internal generation of the field ω_3) also leads to an emission ω_4 on the 4p → 3s transition at 330 nm which may be attributed to the FWM process $\omega_4 = \omega_1 + \omega_2 - \omega_3$. In addition to the parametric generation of ω_4, also parametric amplification at ω_4 related to the amplification at ω_3 can be expected [15]. In the following investigated features of the process, some

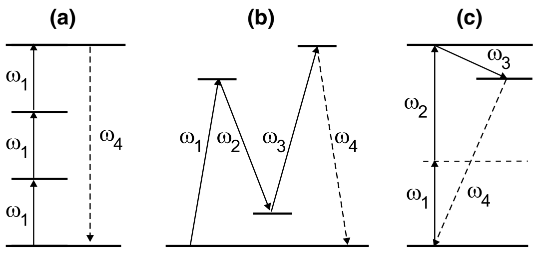

Fig. 1. Mixing schemes: (a) frequency tripling ($3\omega_1 = \omega_4$), (b) double Λ-scheme ($\omega_1 - \omega_2 + \omega_3 = \omega_4$), (c) sum-difference frequency mixing ($\omega_1 + \omega_2 - \omega_3 = \omega_4$).

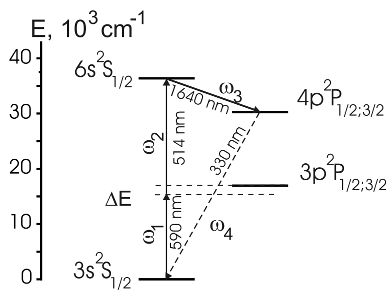

Fig. 2. Simplified energy scheme of atomic sodium with pump and observed lasing transitions. $\Delta E = h\delta\nu_2$ corresponds to a detuning $2\pi\delta\nu_2$ of the pump wave ω_2 with $\delta\nu_2 \approx 400$ GHz. Corresponding wavelengths in nanometers of interacting fields are 590 → 514 → 1640 → 330 for $\lambda_{1,2,3,4}$, respectively.